CFD-BASED DESIGN OF A FILMING INJECTOR FOR N+3 COMBUSTORS

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Motivation for Current Work

- NASA's N+3 (2030 target) Project Goals:
  - Reduce NOx emissions to 80% below ICAO CAEP6 standards
  - "smaller core-size" and "higher T3" as compared to N+2/ERA
  - Evaluate feasibility of drop-in alternate fuels

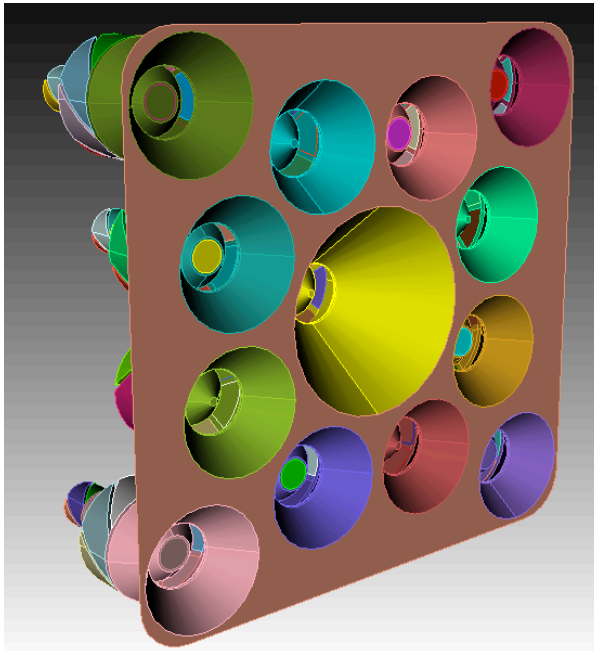
- Lean-Direct Injection (LDI) concepts being studied by OEMs and several injector manufacturers to reduce emissions

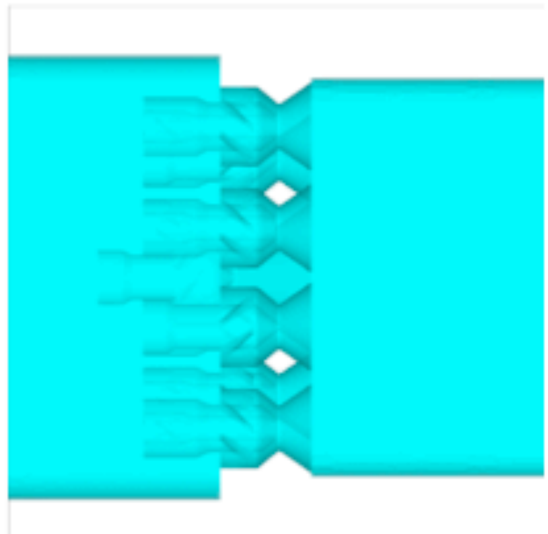
- Current work: Aerodynamic Design of 3rd generation LDI (LDI-3) Injection modules using the National Combustion Code (NCC)

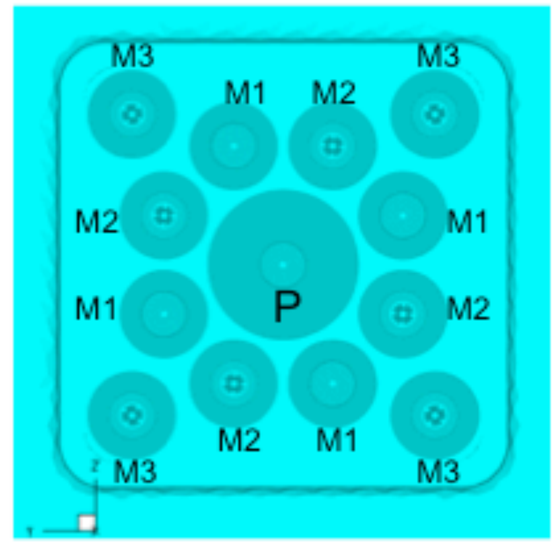
Purpose of Current Work

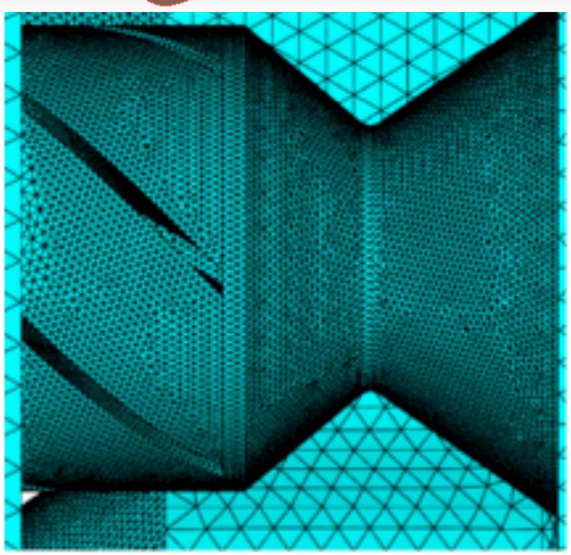
- Use CFD analysis with the NCC to evaluate new, updated injector design(s) to meet NASA's N+3 technology goals
- Impact aerodynamic design of LDI-3 Injection modules
    - Evaluate new Pilot and Main Injection Element design
- CFD predictions of LDI-3 injector performance and emissions
    - – Evaluate filming fuel injection strategy for Main Injection Element

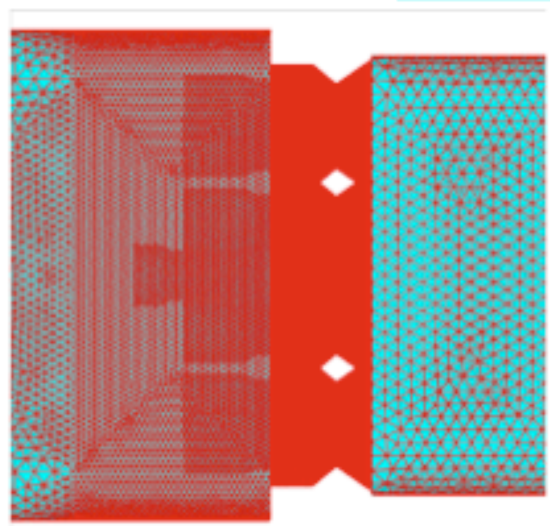
Why use NCC for LDI System Design?









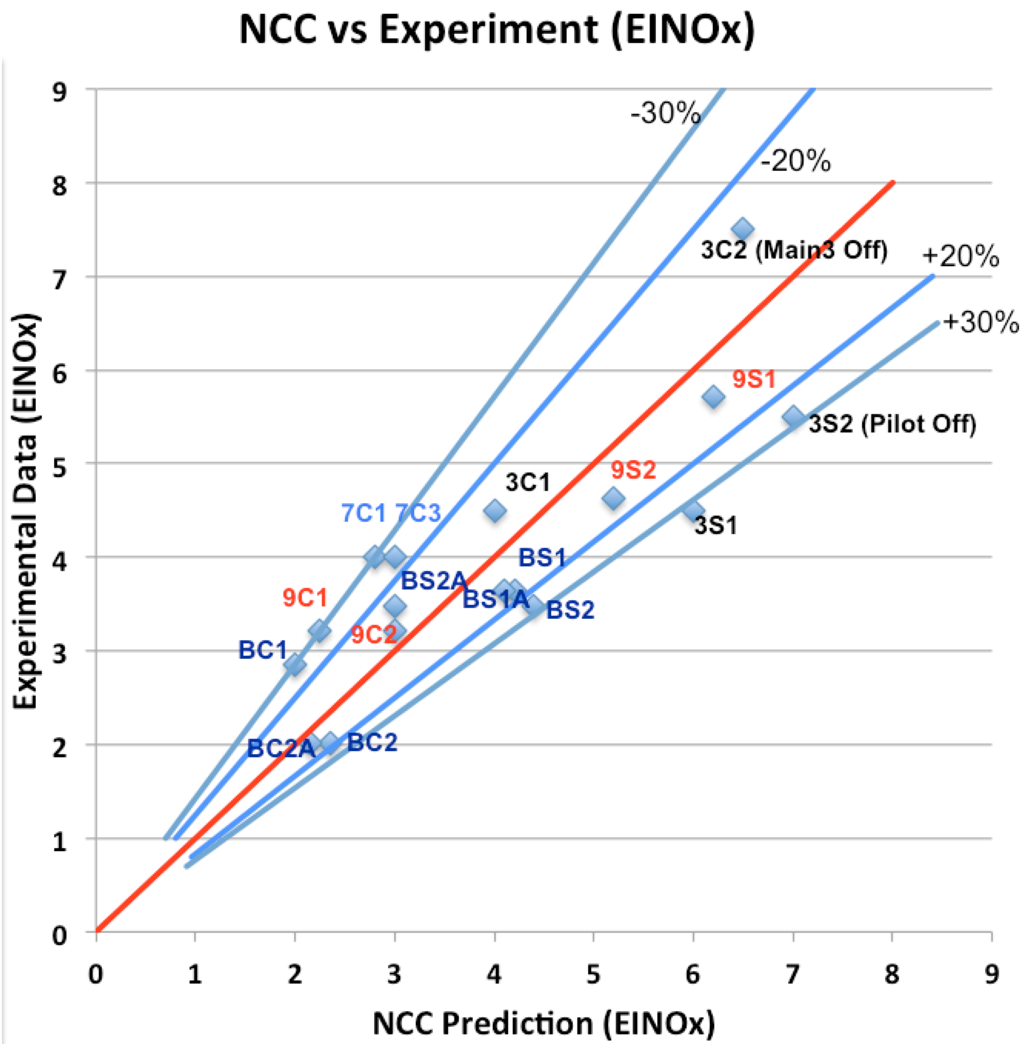


17M element all-tetrahedral mesh

M1 Simplex
M2 Airblast
M3 Airblast
P Simplex

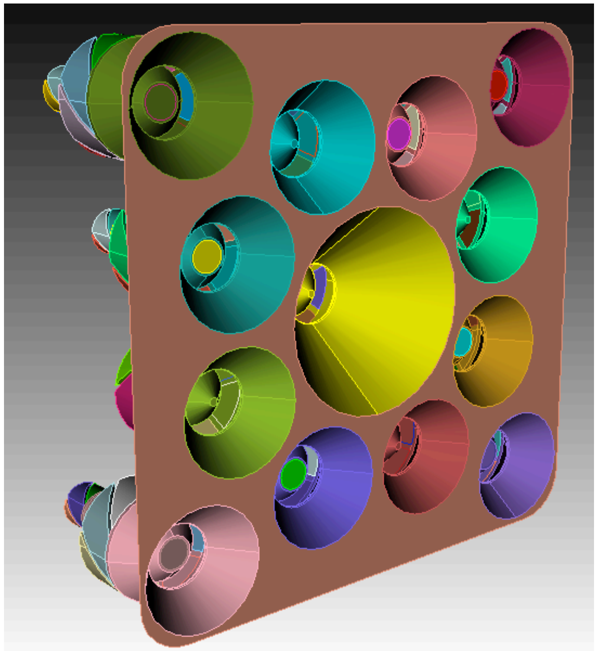
CFD Calibration Results from LDI-2 Data

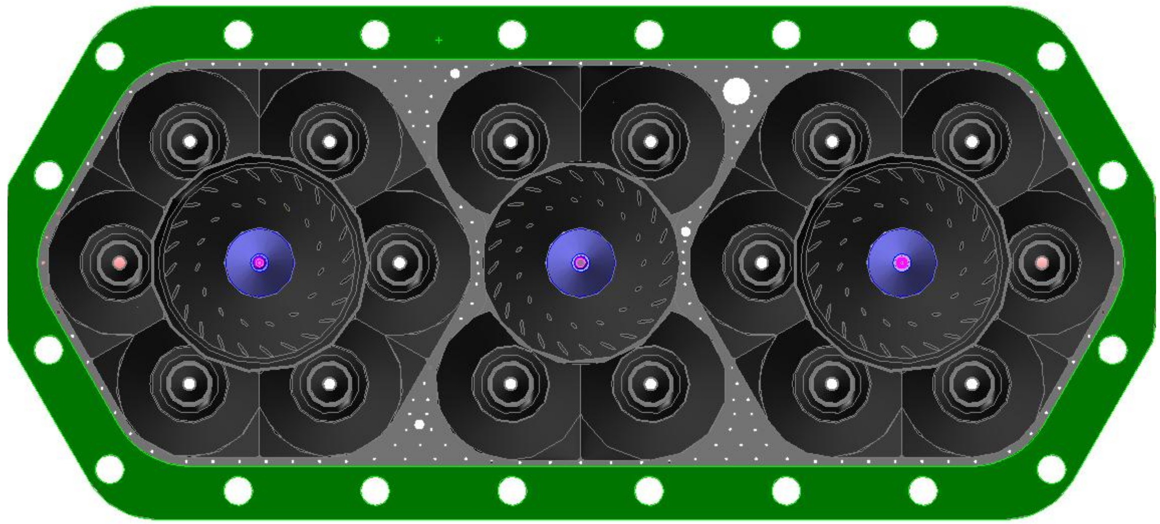
EINOx for 5-pt Recess Configs 3,7,9, Baseline Config 10



NCC CFD Emissions Calibrated for a wide range of N+2 Cycle Operating Conditions

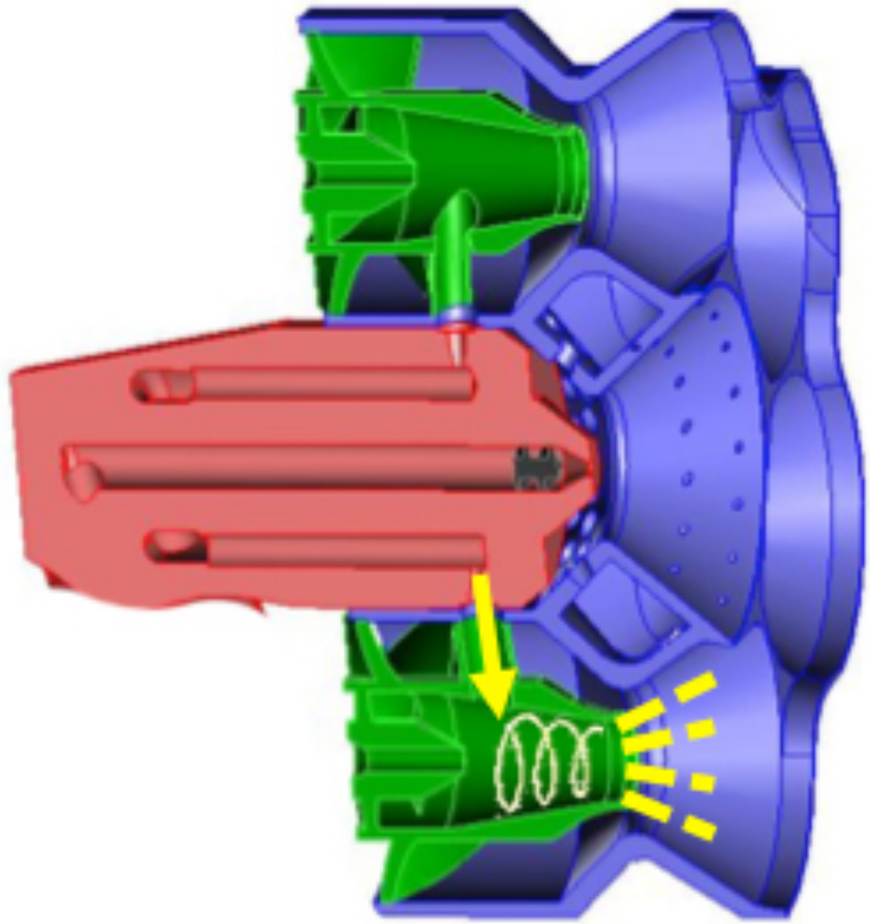
LDI-2 vs LDI-3 Injector Layout





- Large decrease in fuel-injection module complexity with LDI-3 while maintaining effective area of individual injectors
- Much denser packing of injectors at combustor dome face
- Higher reference velocity for LDI-3 due to smaller annulus/ dome area of combustor

LDI-3 Injector Layout



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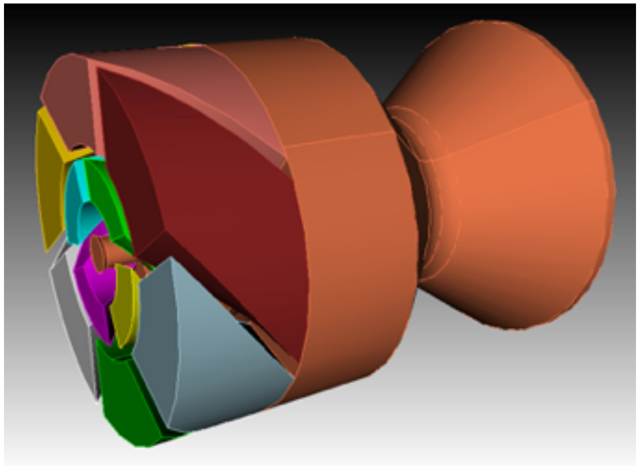
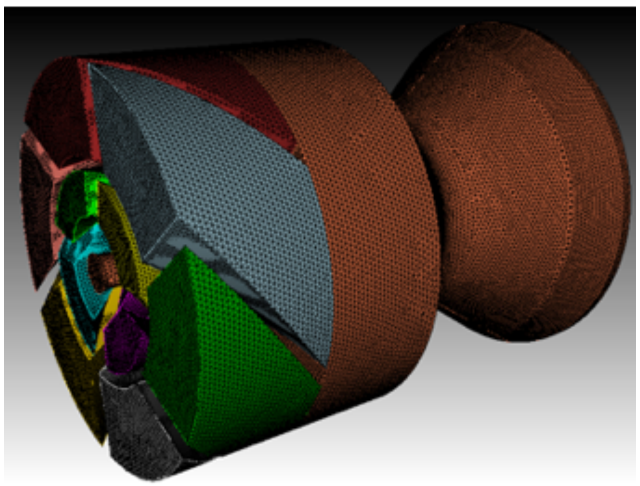
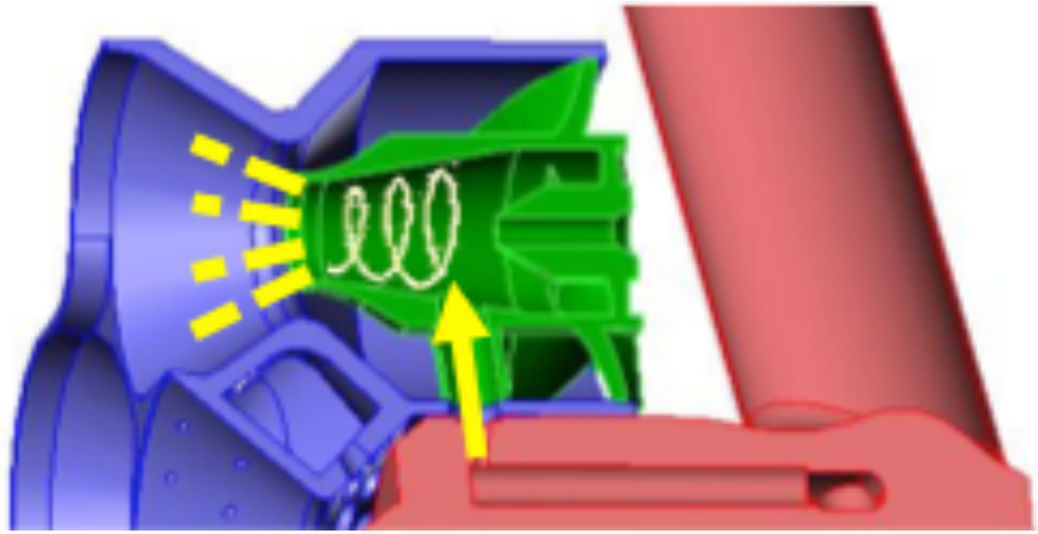
LDI-3 Filming Injector for Main Elements







- Main Injector Air flows through axial bladed swirl venturis
- Two major airflow paths (co-swirling or counter-swirling)
- One center-jet air pathway provides high velocity jet for ‘control’
- Fuel fed tangentially into cross-flowing air-stream of inner air swirlers

Parametric Design Goals with NCC CFD

1. Maximize the total AC_d of the five-element array (Pilot and four Mains)

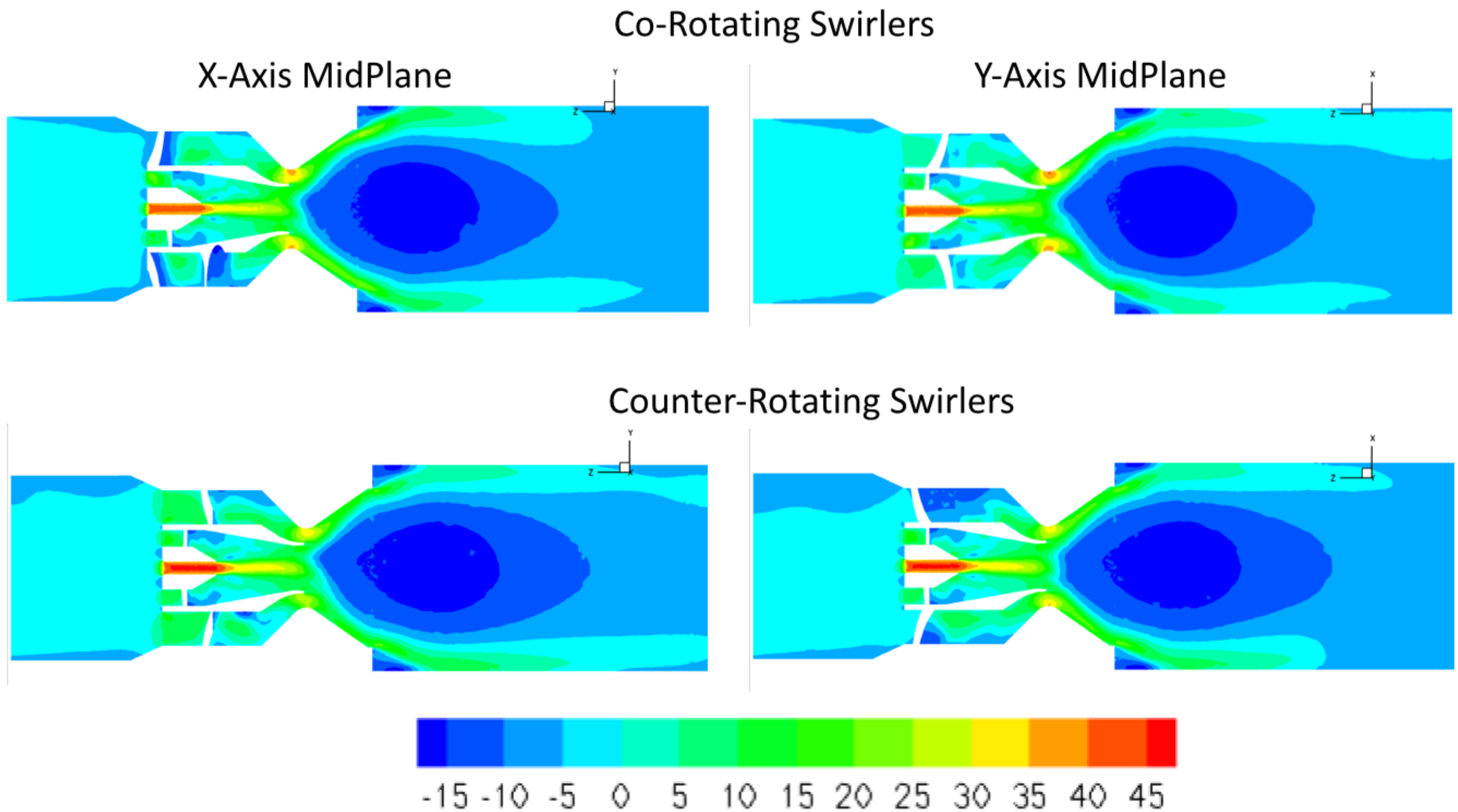
2. Provide an 'optimal' central recirculation downstream of the Pilot

3. Fuel-air mixing and burning in all injector elements to meet N+3 performance, emissions

Summary of National Combustion Code (NCC)

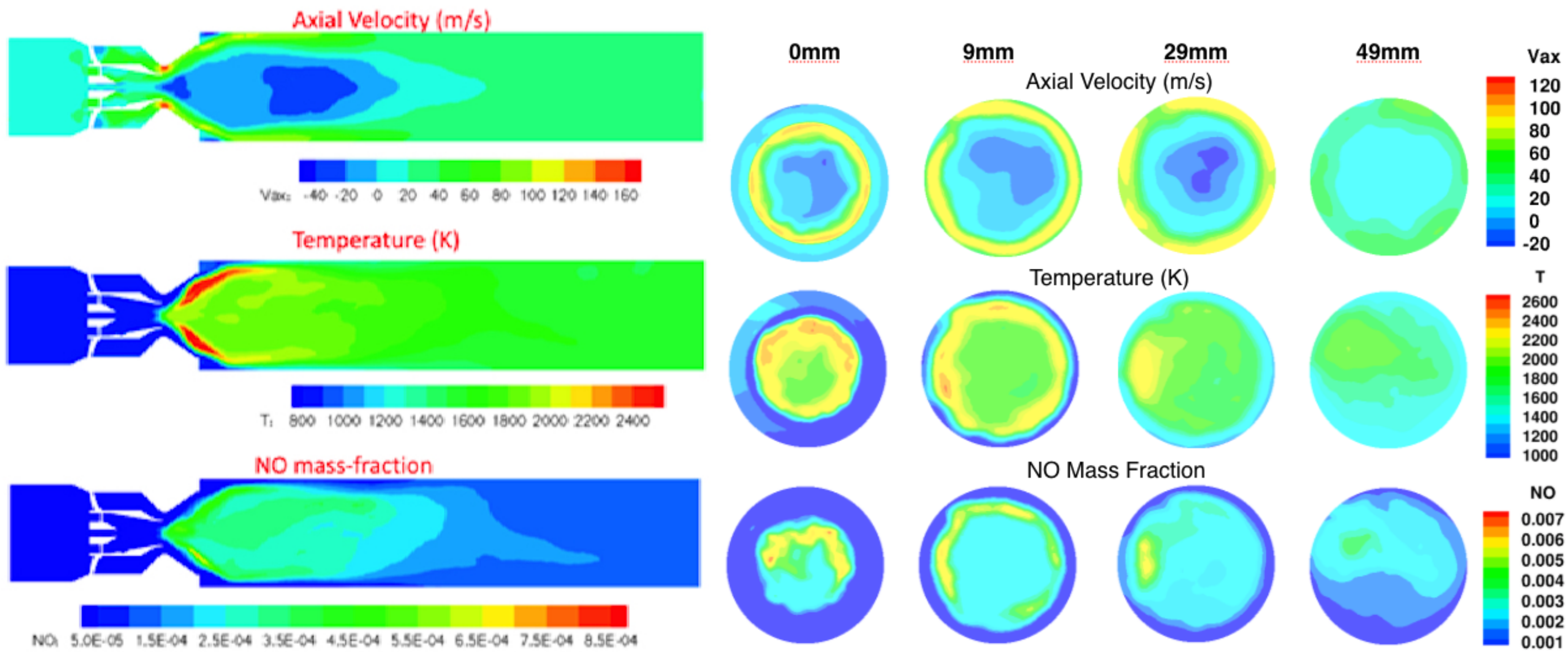
- Finite-Volume solutions of Time-dependent, Navier-Stokes equations
- 2-equation, k-ε turbulence models (non-linear, low-Re or wall-functions)
- Lagrangian spray-modeling with primary/secondary breakup and atomization options, multi-component fuels
- Reduced-kinetics, Finite-rate chemistry models
- RANS time-integration and/or VLES with Time-Filtered Navier-Stokes (TFNS) approach

Parametric I: LDI-3 Single Swirler Design

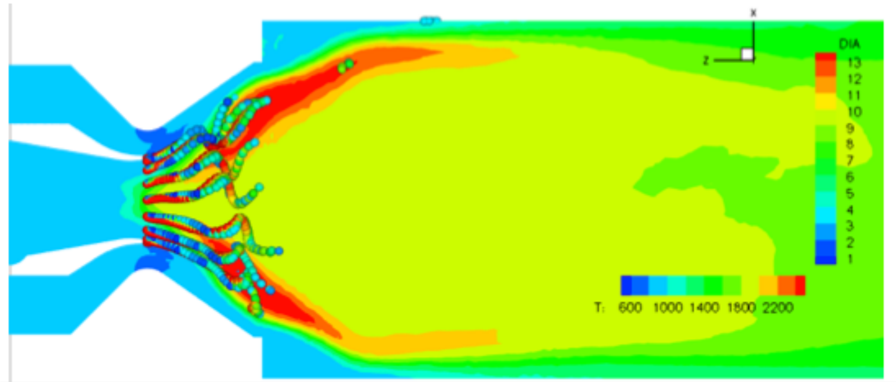


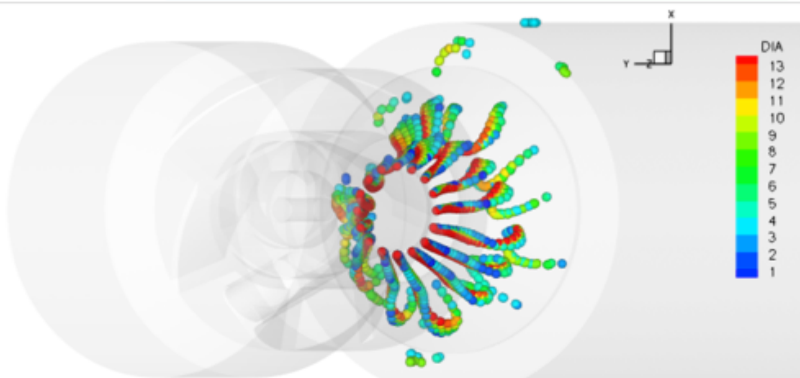
Swirler Configuration	Expt	CFD	Error (%)
52°/60° (OAS/IAS) co-rotating	0.137	0.1411	3.0
52°/60° (OAS/IAS) counter-rotating	0.134	0.1259	-1.1
48°/60° (OAS/IAS) counter-rotating	0.144	0.1467	1.9

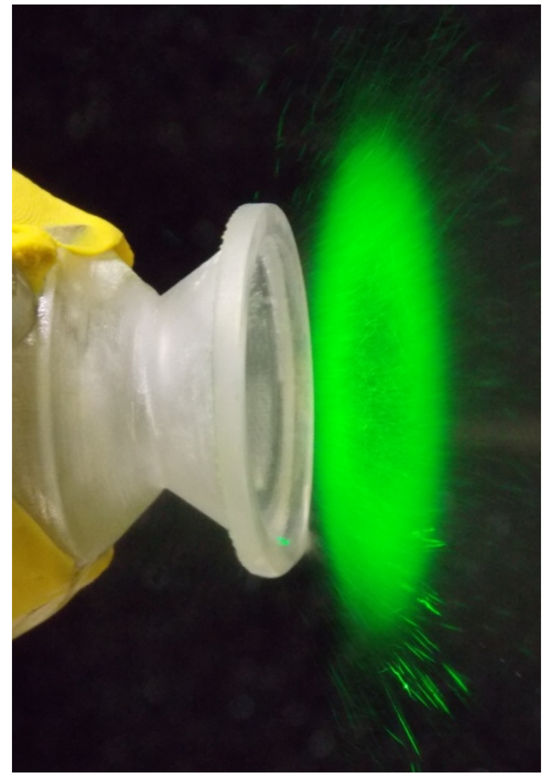
Single-Element Optimization



Single-Element Spray Optimization



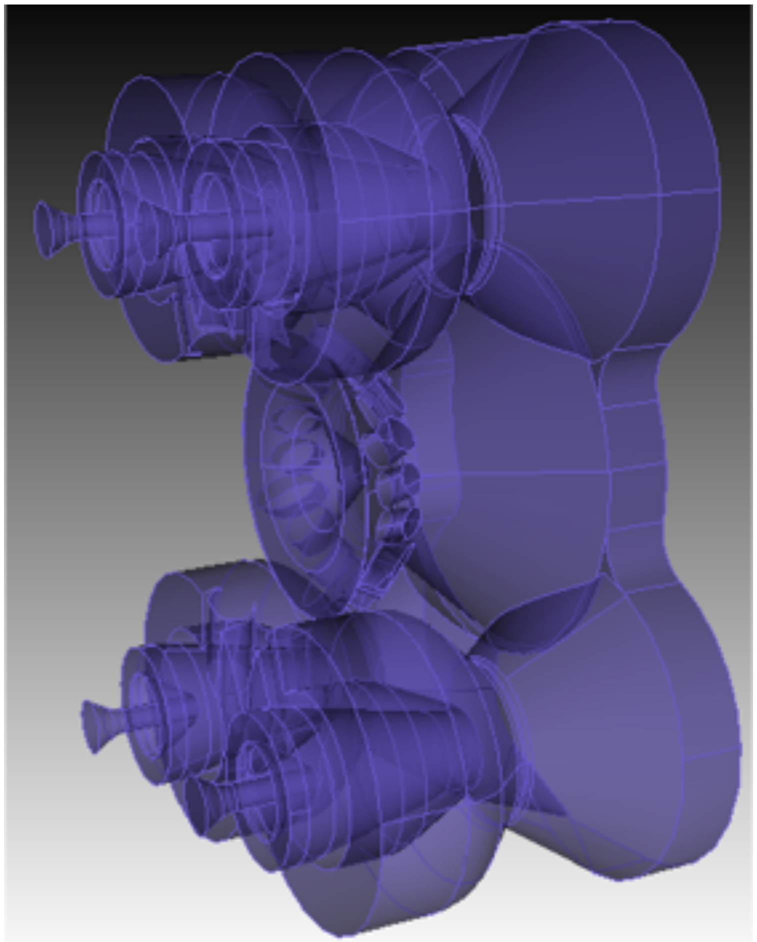


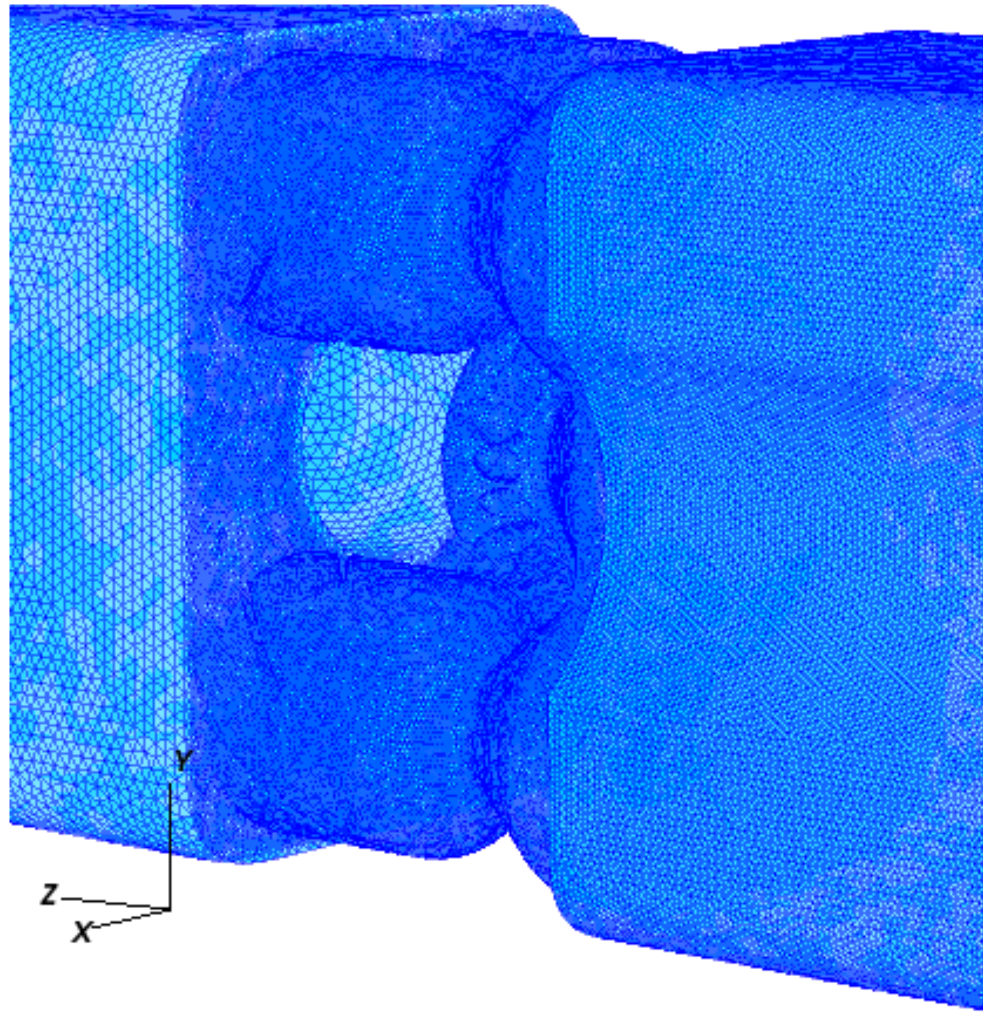


Five-Element Module Design

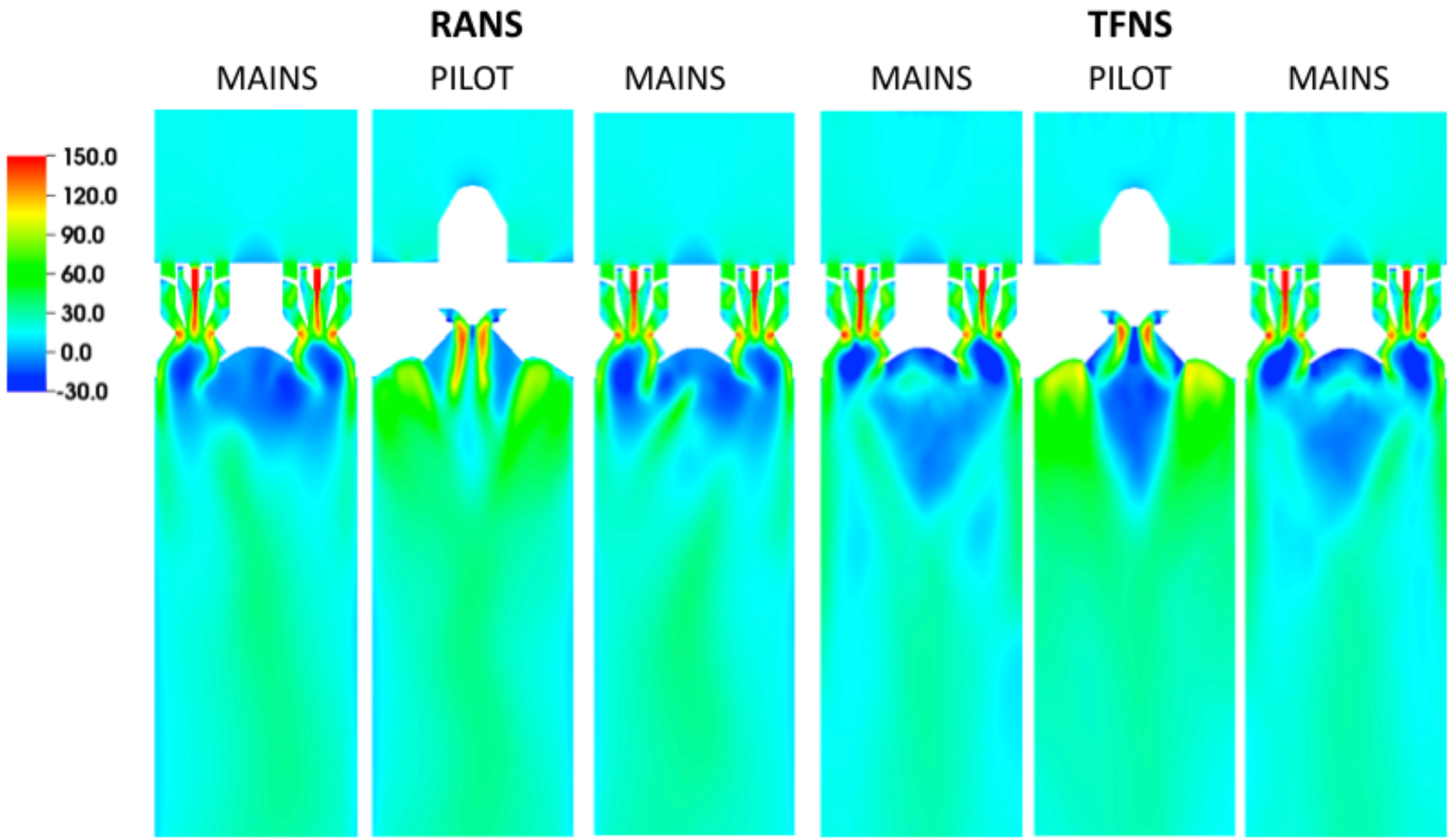
- A central 'Pilot' element (pressure-atomizing injection) and four adjacent 'Main' elements (pre-filming injection)
- Four Main elements with CFD-optimized $48^o/60^o$ outer/inner counter-rotating axial air swirlers
- Central Pilot injector with multiple, radial inflow slots for airflow. Air inflow direction is 51% offset with respect to the injector centerline.
- Two rows of cooling holes on pilot venturi surface, with 18 and 24 cooling holes respectively

Five-Element Module CFD Setup





Non-Reacting Flow: RANS vs TFNS



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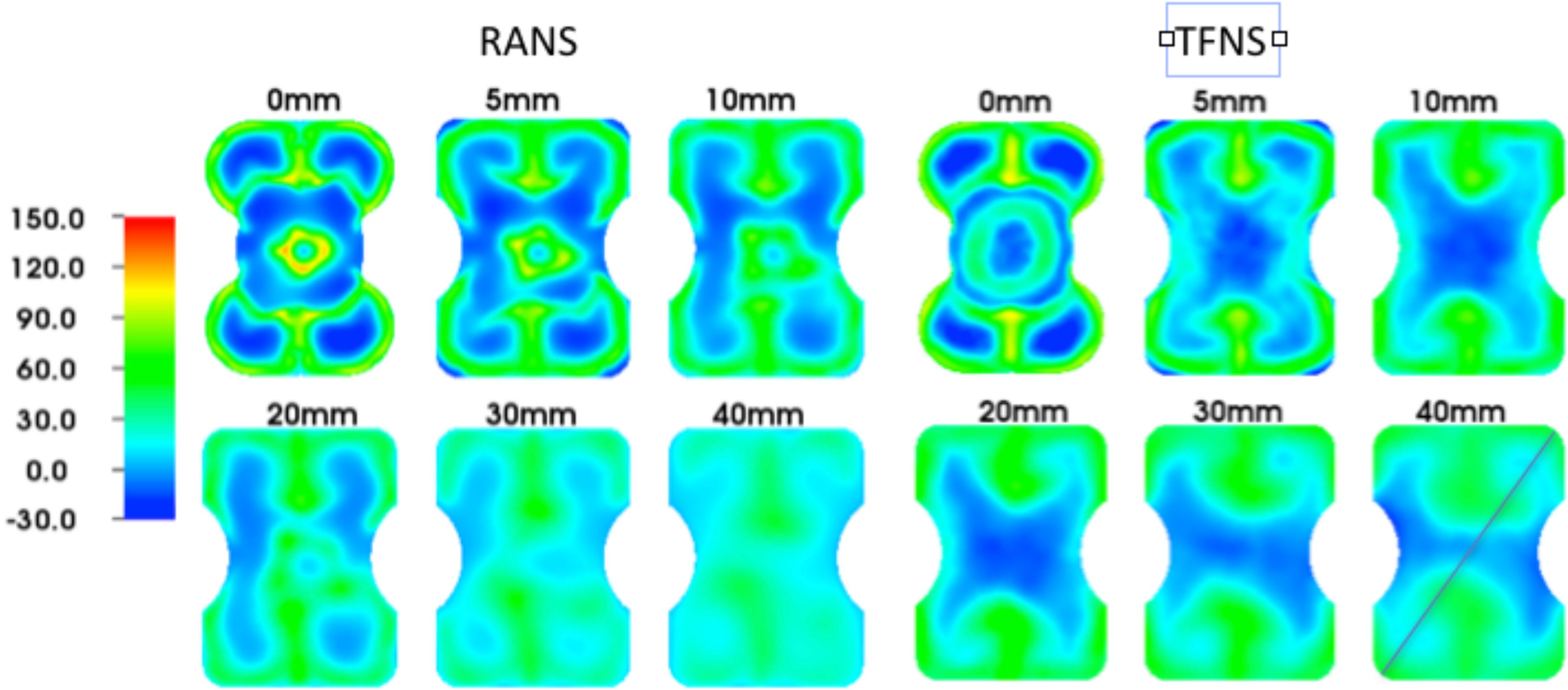
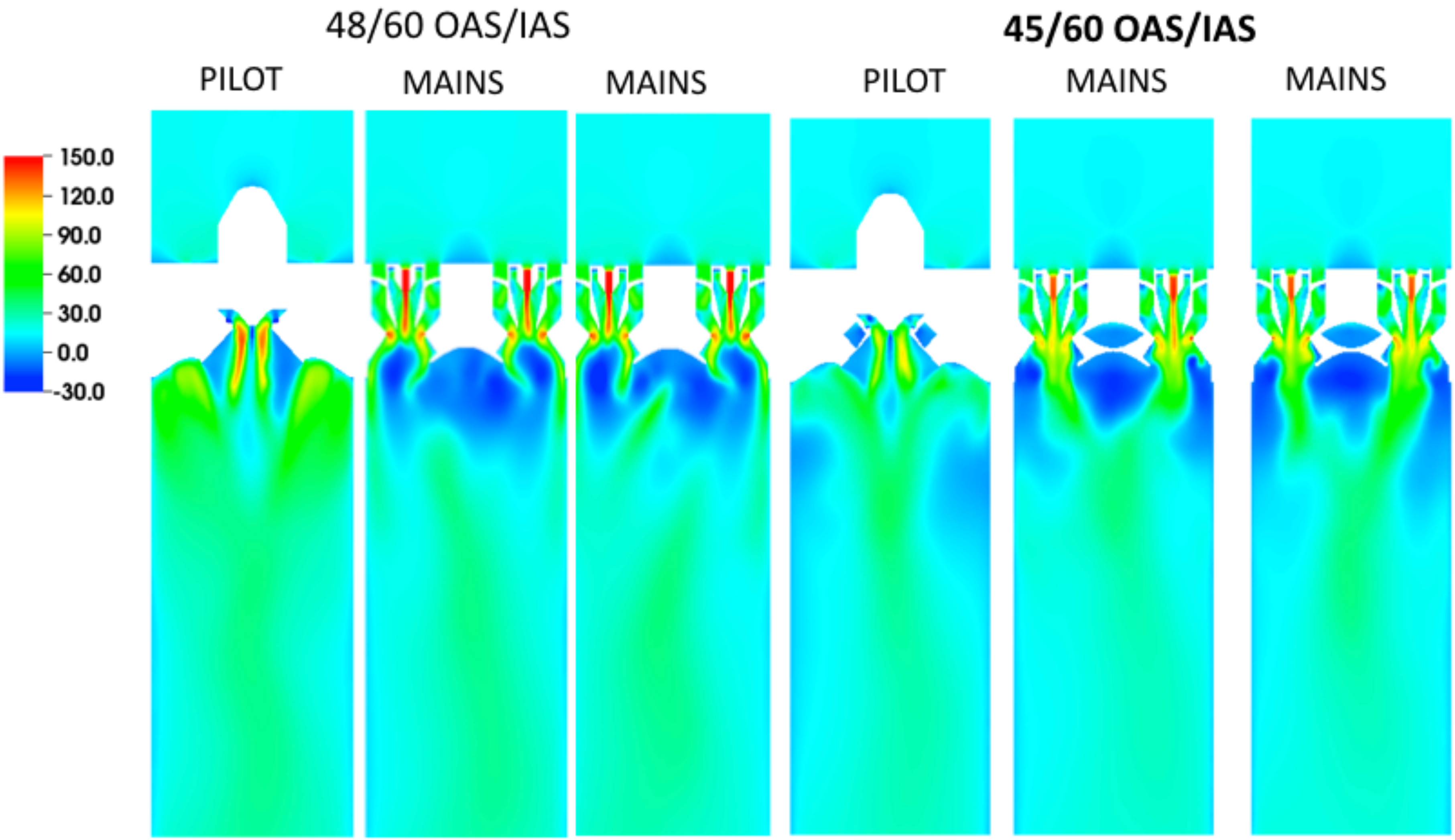
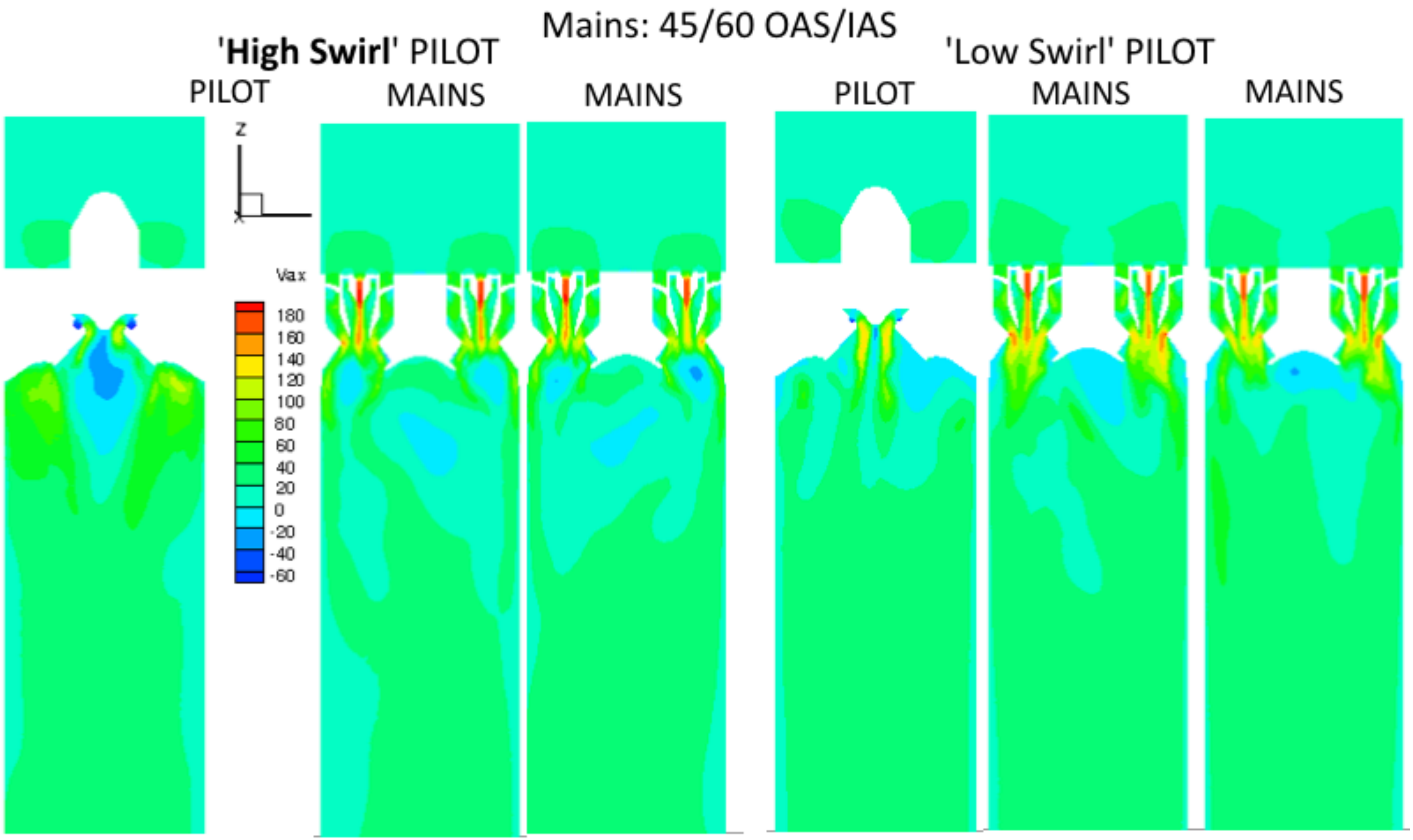


Method	Total (in^2)	Mains (in^2)	Pilot (in^2)	Error (%)
Measured	0.720	0.575	0.145	
NCC RANS	0.744	0.620	0.124	3.3
NCC TFNS	0.752	0.621	0.131	4.4

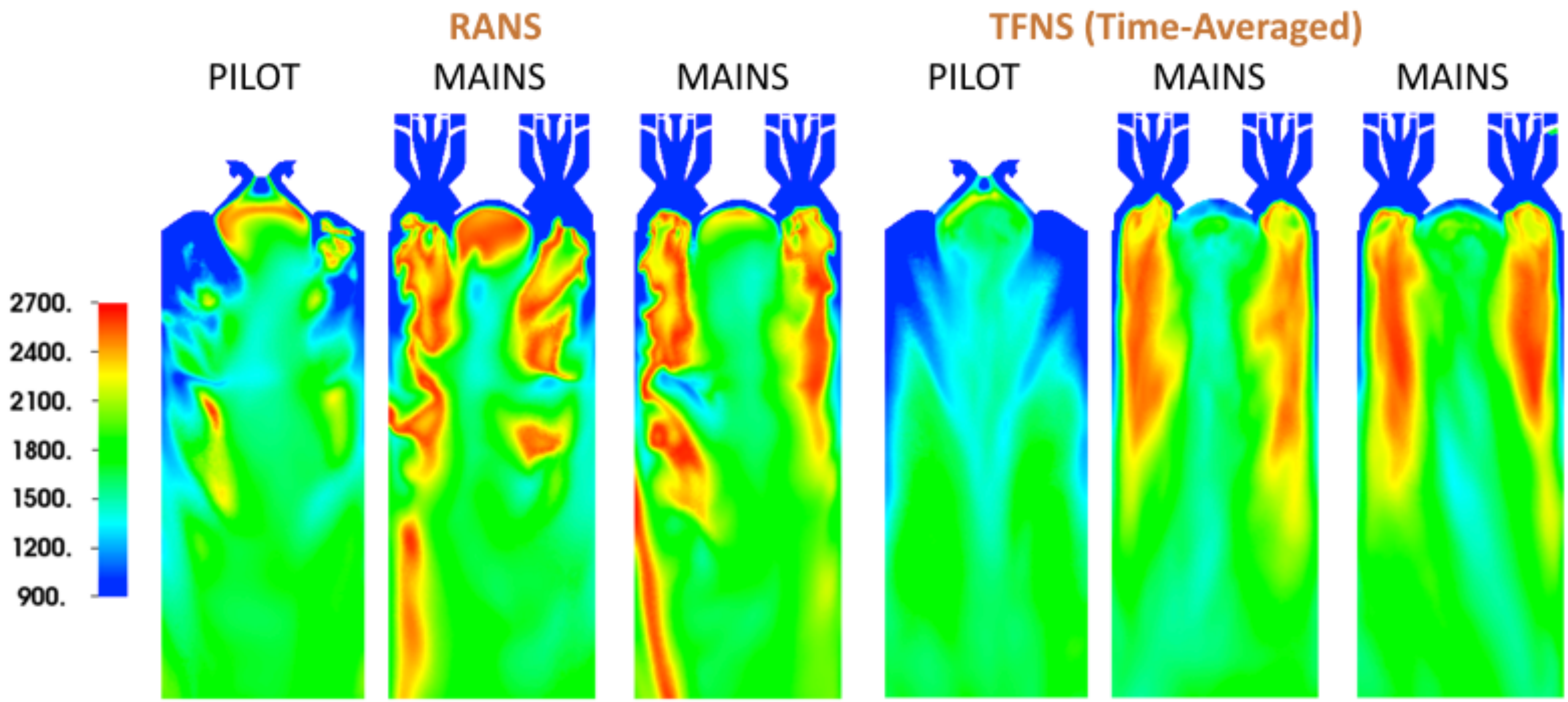
Parametric II: LDI-3 Main Swirlers



Parametric III: LDI-3 Pilot Swirlers



5-Element Module: Reacting Flow



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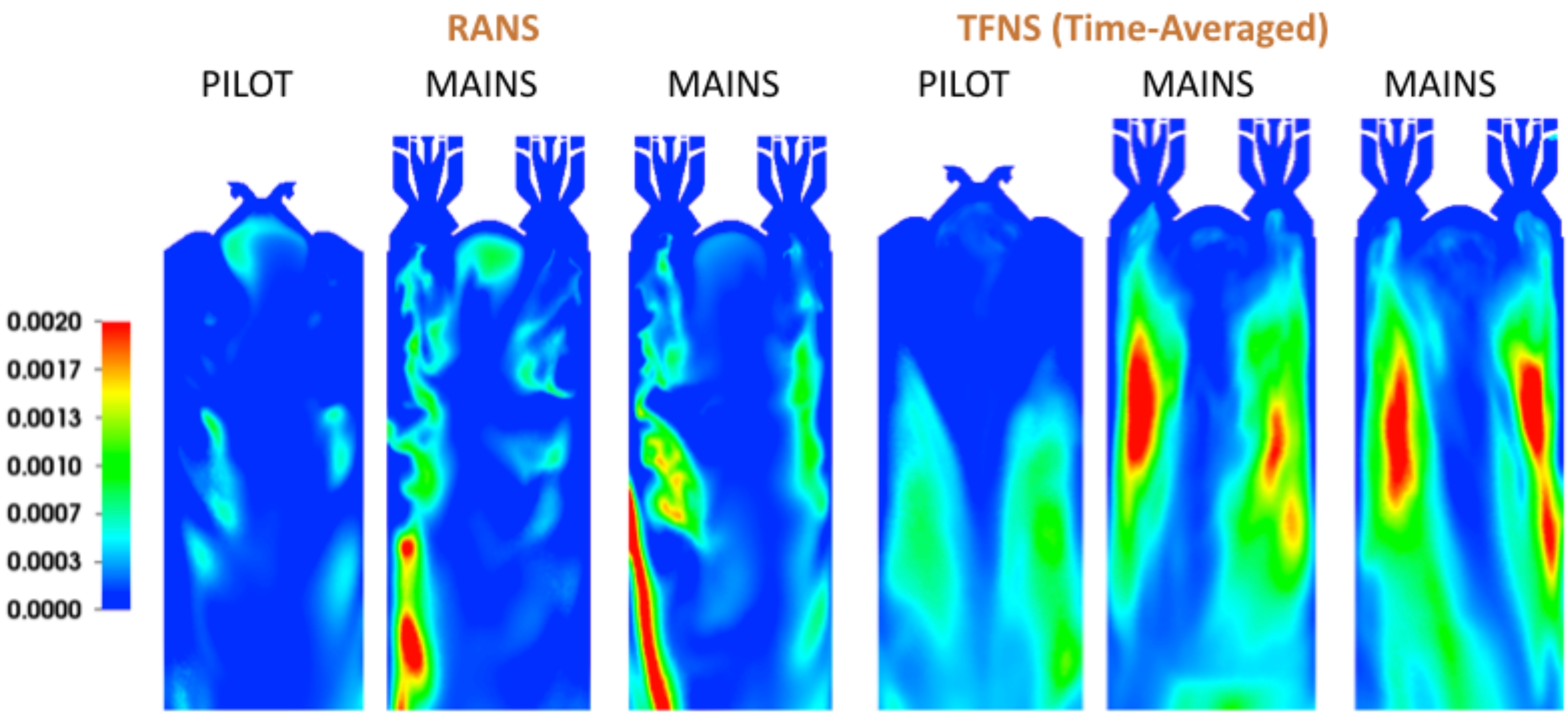
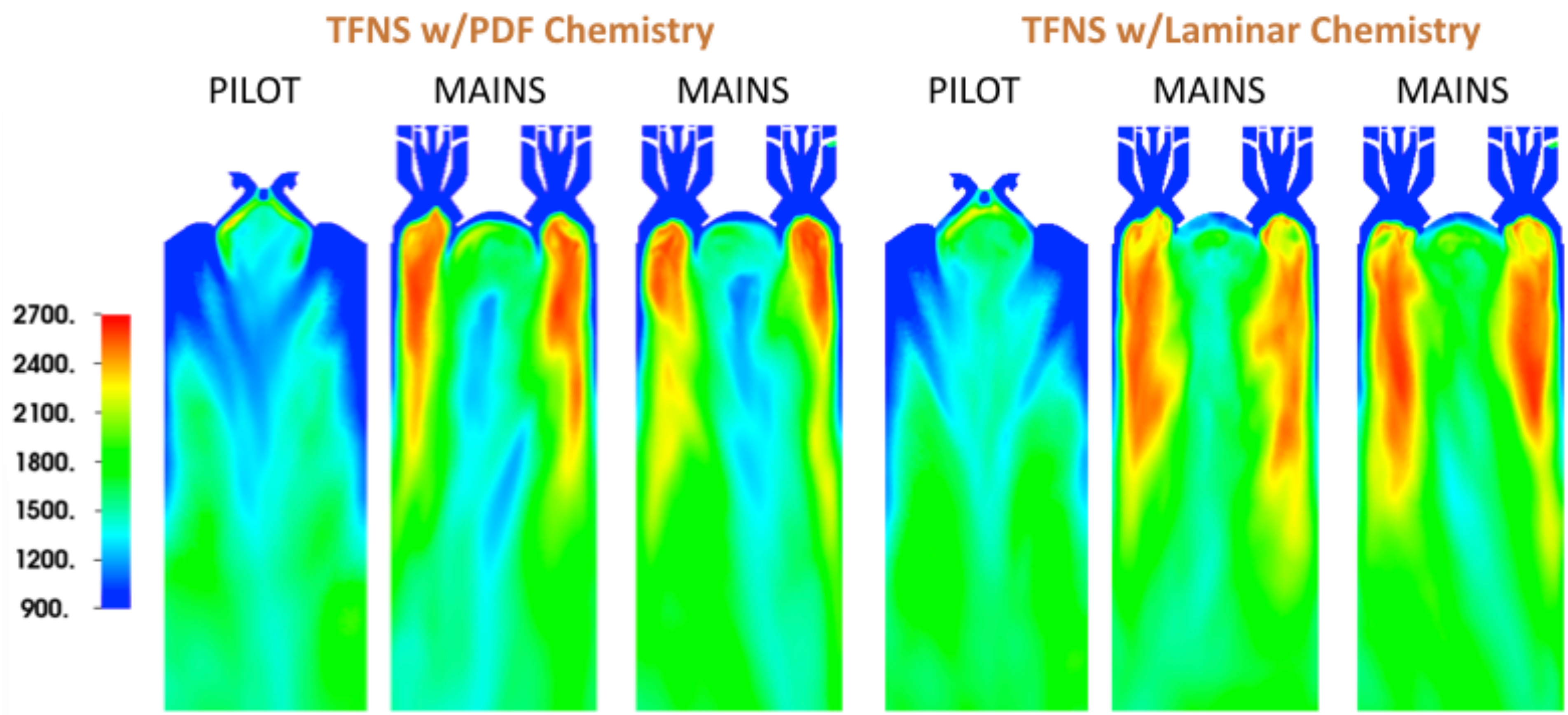


EINOx = 25

EINOx = 29

Effect of Turbulence-Chemistry Interaction (PDF)



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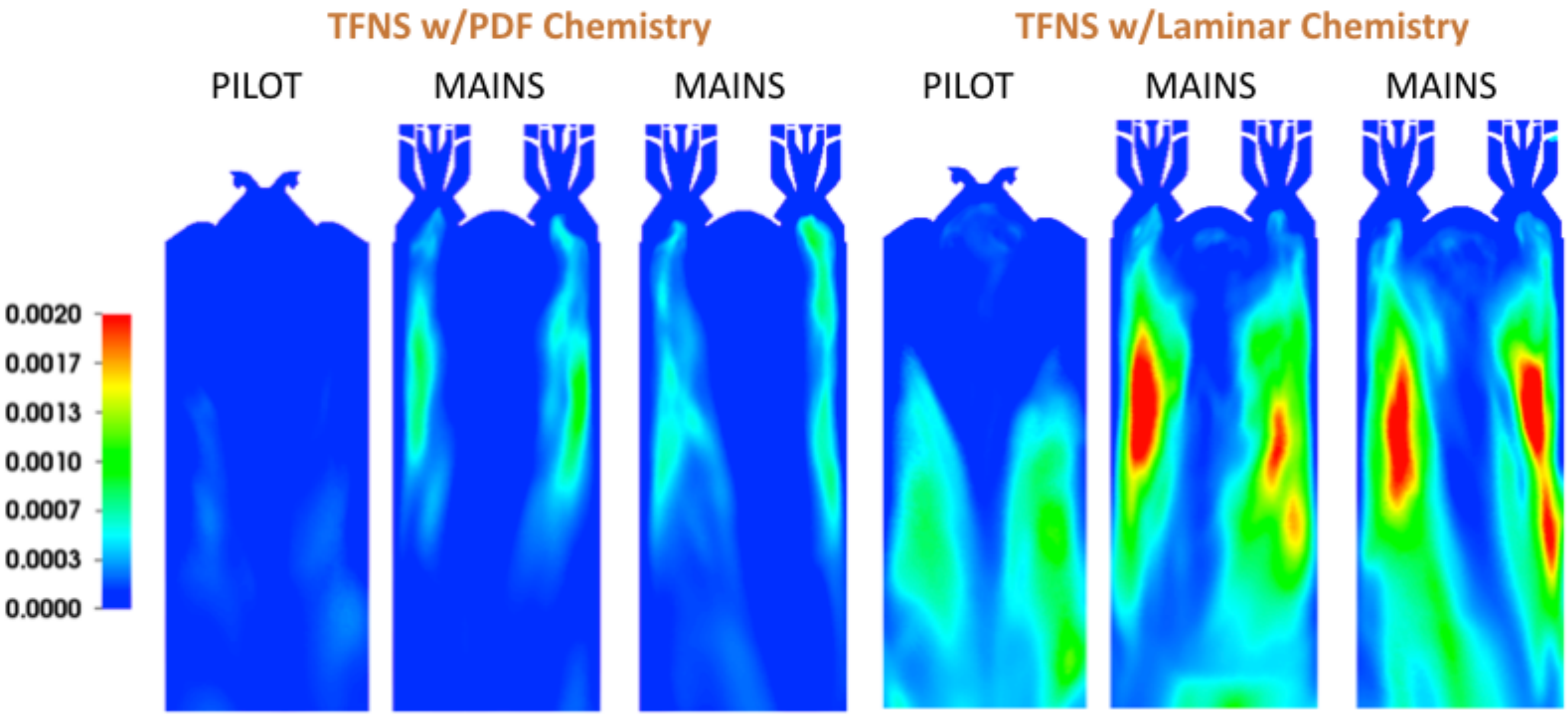

EINOx = 9

EINOx = 29

Summary and Future Work

- NCC CFD shown to be useful to narrow the design matrix for LDI-3 injector aerodynamic design (Main, Pilot Swirlers)
- NCC CFD shown to compare well with experimental data for filming injector spray particle distribution
- Proposed LDI-3 injector redesign improves on LDI-2 injector design with
  - Reduced number of injection elements
  - Reduced Complexity of fueling circuits
  - Better thermal management of fuel system
- Drawbacks of transverse fuel-injection approach (JPC 2015) successfully redesigned with filming-injection approach
- Turbulence-chemistry interaction approach shows large influence of temperature and emissions predictions

Summary and Conclusions

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Future Work

- NCC CFD to be used to evaluate 7-element module of 19-element configuration
- Evaluate NCC CFD turbulence-chemistry interaction models (PDF and LEM) with available LDI-2 experimental database for EINOx predictions
- Investigate sensitivity of CFD solution to spray specifications for modeling of filming injection in main swirlers

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